SIRTF Studies of Exozodiacal Dust : Implications for TPF

TPF Expo
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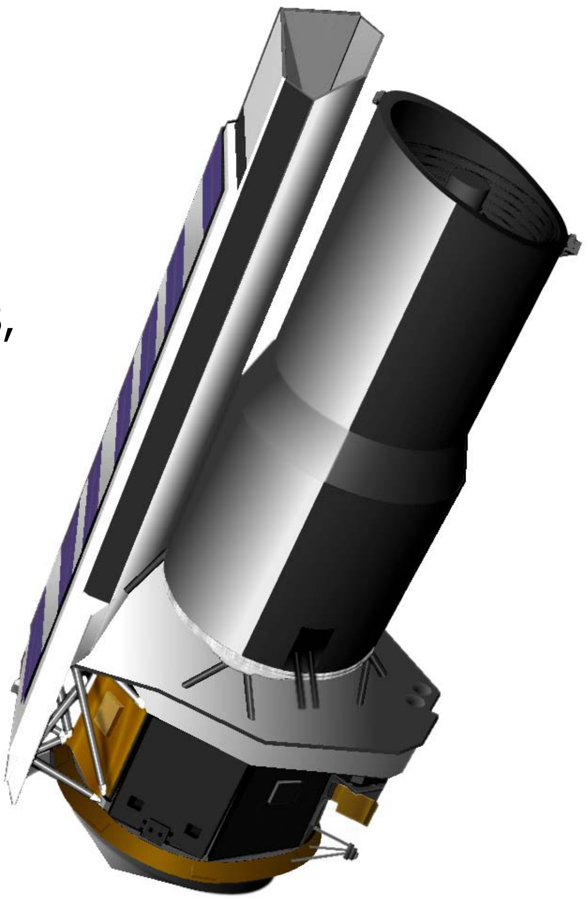
SIRTF and TPF
Project Science Offices
NASA/JPL/Caltech

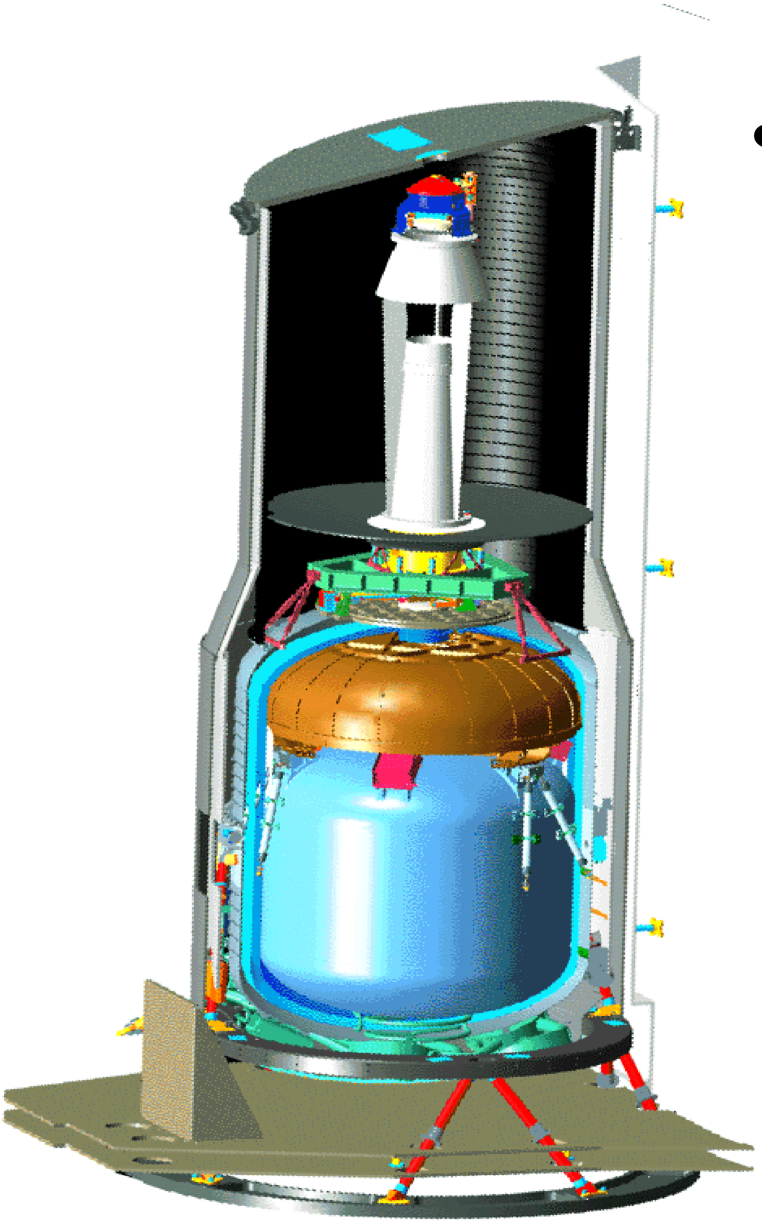
Space Infrared Telescope Facility

- Infrared "Great Observatory"
  - Background Limited Performance 3 -- 180 μm
  - 85 cm f/12 Beryllium Telescope, T < 5.5K
  - 6.5 μm Diffraction Limit
  - Three instruments:
    - Four channel mid-IR camera at 3.5, 4.5, 5.8, and 8.0 μm with 256x256 detector arrays
    - Four module spectrometer, 5-40 μm: R= 50 w/long slit, R= 600 echelle
    - Three channel far-IR camera at 24, 70, and 160 μm; spectrophotometry 50-100 μm
  - Planetary Tracking, 1 arcsec/sec
  - >70% of observing time for the General Scientific Community.



- Full mission info at http://sirtf.caltech.edu

SIRTF: Pathfinder for JWST and TPF-I



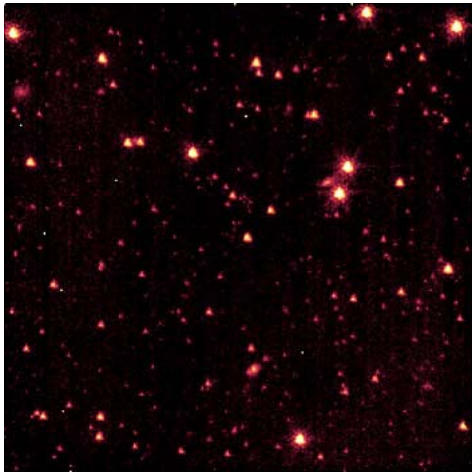
- Warm launch architecture & solar orbit leads to lower mass, more efficient cryogenic system

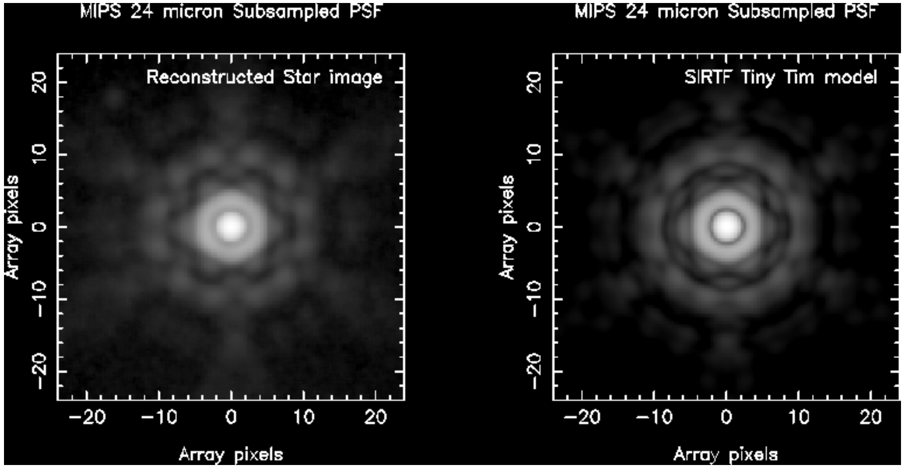
- SIRTF projected lifetime is
  3-5 yrs with 350 liters of He
  [vs. ISO's 2.5 yr with 2100 liters]

  - lightweight cryogenic optics
  - high performance passive cooling
  - state-of-the-art infrared detectors

SIRTF Status Update

- Successful launch into Earth-trailing orbit on 8/25/2003
- The spacecraft is operating nominally
- The cryogenic telescope cooled to 4 K on schedule
- All three instruments are operating; focus adjustment was completed on 10/3/2003; images look very good





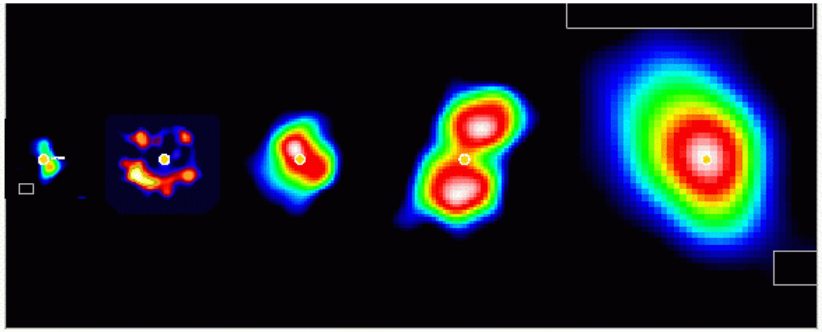
- Transition from checkout activities to routine science operations to occur around Dec. 1
- Early release observations and mission renaming will be presented in mid-December

Exozodiacal dust overview

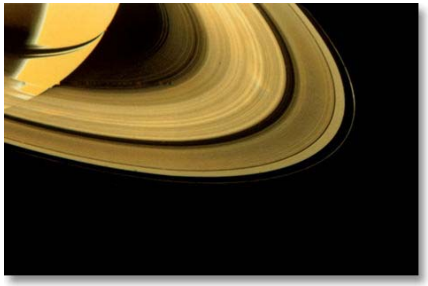
- **In main sequence stars, circumstellar dust indirectly indicates the presence of asteroid/Kuiper belts**
- **These dusty debris disks are most easily identified by far-infrared photometry (IRAS/ISO)**
  - 15-20% of main sequence A stars have far-infrared excess
  - Dust inventories in these identified systems range from 30 to 20,000 times the zodiacal dust level in our solar system
  - ~25 stars within the TPF target sample (d < 20 pc) have known infrared excess; but these are mostly A-F type
  - For main sequence solar-type stars, the circumstellar dust population has yet to be characterized

Structure in Debris Disks:

JCMT images by Greaves, Holland et al.

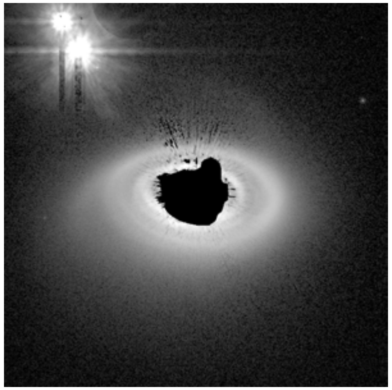


- **Only six debris disks have been spatially resolved at any wavelength !**



- **Even when a planet itself is too faint to see directly, its gravitational influence on its star's dust disk can still be visible, just as small moons sculpt Saturn's rings.**

- **Disk internal structures (warps, central holes, radial gaps, and asymmetries) require dynamical forcing to persist against dispersive forces**



HST/ACS image by Clampin et al.

Debris Disks as a TPF noise source

- **Exozodiacal dust produces thermal emission and reflected light backgrounds, against which planets must be detected.**
- **Can be very significant: a 0.3 AU diameter patch of a 1 zodi cloud has brightness ≈ terrestrial planet**
- **Exozodi can significantly affect integration times:**
  - TPF-I may be restricted to zodi < 30 x solar
  - TPF-C may be restricted to zodi < 100 x solar
- **Clumpy structure in an exozodi cloud could be confused with an actual planet; discriminants are needed**
- **Most important exozodi to TPF is in & around the Habitable Zone:**
- **Dust in a solar system's Kuiper Belt region is not directly a problem for TPF, but is a signpost for planetary debris that may be present throughout the system**
- **SIRTF can quickly survey large target samples for dust**

SIRTF Debris Disk Detection Limits

- **SIRTF' sensitivity is sufficient for 70 μm detections of G2 photospheres at 30 pc distances (10 minutes, 15 sigma) – 100 times better than IRAS**
- **SIRTF has no nulling or coronagraphic capability → all disk detections must be made against bright stellar photosphere**
- **The accuracy of absolute calibration of the MIPS 24, 70, and 160 μm channels will determine the limiting level of exozodiacal dust that can be detected**
- **Si detector (24 μm) : Ultimate goal is 5% calibration**
  - This will enable detection down to the few hundred zodi level
- **Ge detectors (70 and 160 μm): Ultimate goal is 10%**
  - This will enable detection down to the few tens of zodis
- **Above limits are for a G2 star; up to 100x better for A stars**
- **Above limits are for a continuous disk; could be much worse if the disk has a large central hole**

SIRTF observations of TPF Targets

- TPF target lists are still being defined
- Perhaps ~60 likely TPF targets within 20 pc are already slated for SIRTF far-IR photometry
- To fully survey the ~150 likely targets of the full TPF mission, additional observing time will be sought in future observing cycles (GO proposals due Feb. 14 2004)
- Characterization of the exozodi may not be possible for stars in regions of high infrared background
- Surveys for brown dwarf companions will be carried out for the near (d < 5 pc) and late-type (K5+) targets. Might be able to find wide (> 10”), cold (T_{eff} < 600 K) objects at λ= 4.5 μm that are undetected in groundbased surveys

SIRTF Studies of Disk Frequency

- **Photometric & Spectroscopic survey of 150 nearby FGK stars**
  - Includes 40 stars with radial velocity planets; will be first quantification of the disk/planet connection
  - Most relevant sample to TPF
- **Photometric survey of 50 nearby M stars**
  - First assessment of disk frequency in most common stellar type
- **Photometric survey of 70 main sequence binaries with F-type primaries**
  - Will begin to assess dependence of disk properties on binary separation
- **Photometric survey of 150 main sequence A stars**

SIRTF Studies of Disk Evolution

- Photometry & spectroscopy of 350 FGK stars of various ages (FEPS Legacy Program)
- Photometry of 140 A stars of various ages
- Photometry of multiple samples of young stars:
  - Nearby young field stars (50 targets, ages < 1 Gyr)
  - Beta Pic, Castor, Ursa Major, Tucanae, TW Hya, η Cha moving groups / associations (300 targets, ages 10-200 Myrs)
  - X-ray selected Weak-line & post T Tauri stars (160 targets, ages 3-30 Myrs)
  - > 1000 targets in young clusters with ages 1-80 Myrs
- Spectroscopy of dust grain properties in >600 selected YSO and debris disks – chemical state of protoplanetary material and dusty debris

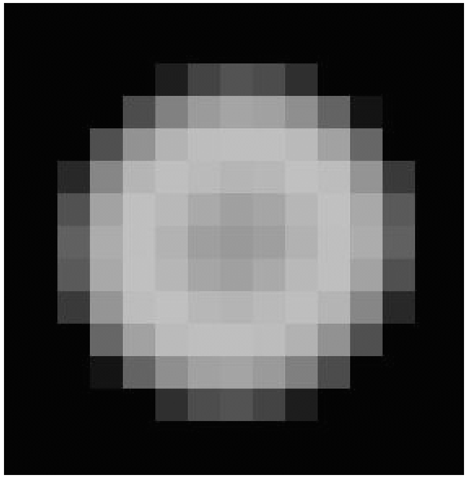
Disks that SIRTF will spatially resolve

- **SIRTF has very limited angular resolution at the wavelengths of disk extended emission:**
  - 5.6 arcsec @ 24 μm (blackbody peak T ~120 K)
  - 16 arcsec @ 70 μm (blackbody peak T ~40 K)
  - 38 arcsec @ 160 μm (blackbody peak T ~20 K)
- **The "Fabulous Four" debris disks already resolved by IRAS and JCMT are resolvable: β Pic, Vega, Fomalhaut, and ε Eri**
- **An additional "Dirty Dozen" disks discovered but not resolved by IRAS should be large enough to resolve with SIRTF:**

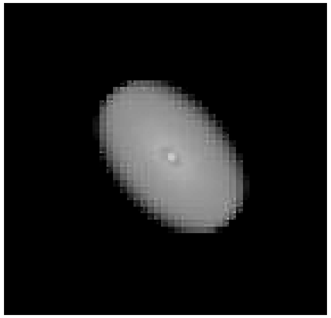
Star name	SpT	dis	tau	Notes
Alpha CrB	A0	23	620	*Ecl binary; P=17d, G type*
Beta Leo	A3	13	190	*Most extended after Fab4*
Beta UMa	A1	24	280	
Delta Vel	A0	25	28	*Ecl binary, P=45d, A type*
Gamma Oph	A0	29		
Tau3 Eri	A4	26	75	
Tau Cet	G8	3.5	120	*Solar type*
Zeta Lep	A3	21	710	*Evidence for hot dust*
Eta Tel	A0	48		
Gam Tri	A1	36		
Alpha Pic	A7	30	90	

SIRTF Resolution Examples: ε Eri and τ Ceti

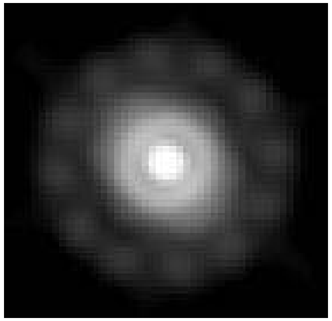
- **Epsilon Eri disk model: Face-on axisymmetric dust ring with size matching JCMT observations, and optical depth implied by fractional IR luminosity**
- **Stellar point source included, but not noise**
- **MIPS 70 μm fine scale, no oversampling**



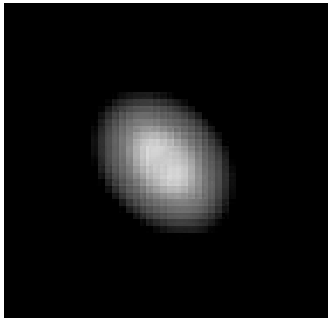
- **Tau Ceti disk model:** Axisymmetric dust disk with inner radius 20 AU, outer radius 100 AU, matching the IRAS 60 micron flux density and optical depth implied by fractional IR luminosity.
- MIPS 70 μm fine scale, subsampled; STinyTIM PSF used
- Noiseless image; perfect PSF subtraction.



Disk model



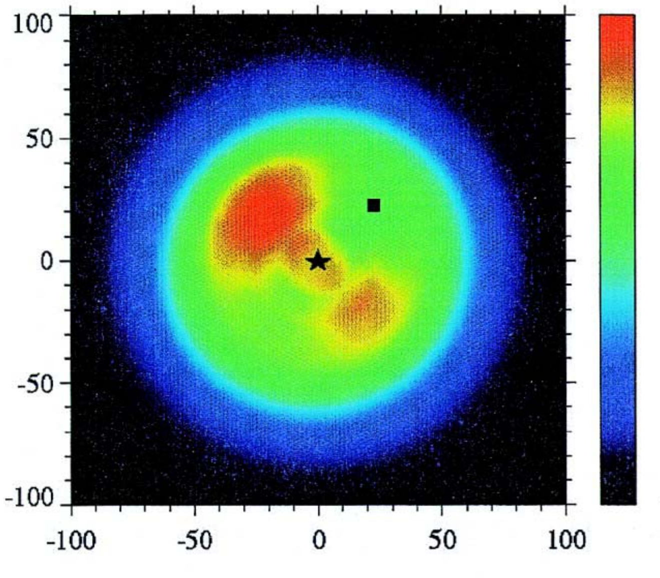
Convolved



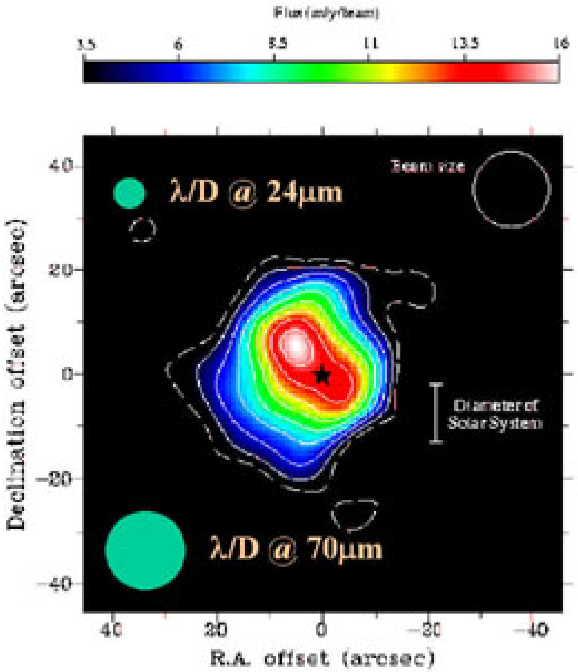
PSF subtracted

Disk asymmetries suggest perturbing objects

Dynamical simulation of dust asymmetry induced by a planet in a face-on disk (Ozernoy et al.)



JCMT Vega image in comparison to SIRTF beamsizes



Prospectus for 2006

- **SIRTF will have observed all likely TPF targets and photometrically characterized their exozodi**
- **SIRTF's broader studies of disk frequency and evolution will lead to a better understanding of planet formation in a variety of astrophysical contexts**
- **SIRTF will have spatially resolved a few dozen debris disks and characterized their substructure**
- **HST and AO imaging of disks newly discovered by SIRTF will yield additional new info on disk substructure**
- **Next summer, come get an early view of SIRTF results on debris disks and exozodiacal dust:**
  - TPF/Darwin Inernational Conference July 26-29 2004, San Diego: "Dust Disks and the Formation, Evolution, and Detection of Habitable Planets" – http://planetquest.jpl.nasa.gov/TPF_darwin

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FINISH